Radial Tears of the Lateral Meniscus—Two Novel Repair Techniques

A Biomechanical Study

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Background: A common treatment for radial tears of the meniscus has historically been partial meniscectomy. Owing to the poor outcomes associated with partial meniscectomy, repair of the meniscus is an important treatment option. It is important to evaluate different repair techniques for radial tears of the meniscus.

Purpose/Hypothesis: The purpose of this study was to evaluate 2 novel techniques to repair radial tears of the lateral meniscus. The 2 techniques were compared biomechanically with the cross-suture method with an inside-out technique. The authors hypothesized that novel repair techniques would result in less displacement after cyclic loading, increased load required to displace the repair 3 mm, greater load to failure, decreased displacement at load to failure, and increased stiffness of the repair, resulting in a construct that more closely re-creates the function of the intact meniscus.

Study Design: Controlled laboratory study.

Methods: A total of 36 fresh-frozen cadaveric tibial plateaus containing intact menisci were obtained. The menisci were divided into 3 groups (n = 12 in each group), and each meniscus was repaired simulating an inside-out technique. The 3 repairs completed were the hashtag, crosstag, and cross-suture techniques. Radial tears were created at the midbody of the lateral meniscus and repaired via the 3 techniques. The repaired menisci were attached to an axial loading machine and tested for cyclic and failure loading.

Results: After cyclic loading, the cross-suture repair displaced 4.78 ± 1.65 mm; the hashtag, 2.42 ± 1.13 mm; and the crosstag, 3.13 ± 1.77 mm. The hashtag and cross-tag repairs both resulted in significantly less displacement (P = .003 and .024, respectively) as compared with the cross-suture repair. The cross-suture technique had a load to failure of 81.43 ± 14.31 N; the hashtag, 86.08 ± 23.58 N; and the crosstag, 62.50 ± 12.15 N. The cross-suture and hashtag repairs both resulted in a greater load to failure when compared with the crosstag (P = .009 and .009, respectively). There was no difference comparing the load required to displace the cross-suture technique 3 mm versus the hashtag or crosstag technique (P = .564 and .094, respectively). However, when compared with the crosstag technique, the hashtag technique required a significantly greater load to displace the repair 3 mm (P = .015).

Conclusion: This study introduced 2 novel repair techniques—hashtag and crosstag—that did not demonstrate superiority in terms of load to failure or stiffness, but both repairs were statistically superior to the cross-suture repair in terms of displacement after cyclic loading. Considerations that may influence the validity of these techniques include cost, surgical time, and increased technical demand.

Clinical Relevance: Radial tears of the meniscus are difficult to repair. Further research into more stable constructs is necessary.

Keywords: radial tear; lateral meniscus; inside-out meniscal repair

Once thought to be a structure of uncertain importance, the meniscus is now known to play an integral role within the knee joint.[24,25,28] Load distribution, shock absorption, proprioception, lubrication, nutrient distribution, and joint stability have all been attributed to the functionality of the meniscus.[1-3,8,19,22,24,25,28-31] Composed mainly of circumferentially oriented type 1 collagen fibers, the structure of the meniscus allows for dispersion of compressive and hoop stress forces that have been implicated in premature articular cartilage degeneration in patients with prior meniscectomy.[1,4,16,18,19] Radial tears are relatively common, and they represent a unique subset of meniscal

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pathology.[12,13,21] Complete radial tears transect the circumferential collagen fibers responsible for load distribution and dispersion of hoop stresses and thus have been shown to be functionally equivalent to a total meniscectomy.[26] The surgical treatment of radial tears has traditionally been arthroscopic partial meniscectomy.[9,10,12,13,23] However, several authors have described deleterious biomechanical changes associated with partial meniscectomies.[6,7,19,26] Bedi et al[9] reported contact areas and peak pressures of partial meniscectomy that were not significantly different from a 90% lateral meniscus radial tear and concluded that preservation of the lateral meniscus is indicated whenever possible.

There is a paucity of data describing repair techniques of radial meniscal tears.[13] Lee et al[20] compared the conventional inside-out repair with an all-inside method; these authors found that there was no significant statistical difference between the methods in displacement and gapping during submaximal cyclic loading, as well as no significant statistical difference in load-to-failure testing. In a human cadaveric study of 6 knees, Bedi et al[8] reported that surgical repair of radial lateral meniscal tears with an inside-out method with 2 horizontal mattress sutures failed to restore contact mechanics of the intact knee. Matsubara et al[23] compared the standard double horizontal suture technique with a novel cross-suture technique. The cross-suture technique demonstrated a significantly higher failure load and stiffness and a significantly lower displacement after cyclic loading. The authors attributed these results to the oblique orientation of the sutures in relation to the circumferential collagen fibers.

To our knowledge, no study to date has demonstrated a lateral meniscal repair technique that has restored pressure and load distribution equivalent to the native meniscus. The menisci in vivo are challenged by a dynamic combination of compressive and shearing forces that underscore the necessity for primary stability.[20] By potentially increasing the stability of a meniscal repair, it might be possible to more closely re-create the state of an intact meniscus. The purpose of this study was to biomechanically evaluate 2 novel techniques to repair radial tears of the midbody of the lateral meniscus. The 2 novel techniques were compared with the cross-suture method described by Matsubara et al,[23] using an inside-out technique. The following variables were measured: displacement at the repair site after cyclic loading, load required to displace the repair 3 mm, load to failure, displacement at load to failure, and stiffness of the repair. We hypothesized that the 2 novel repair techniques would result in superior biomechanical stability based on 2 parameters: cyclic loading and load to failure.

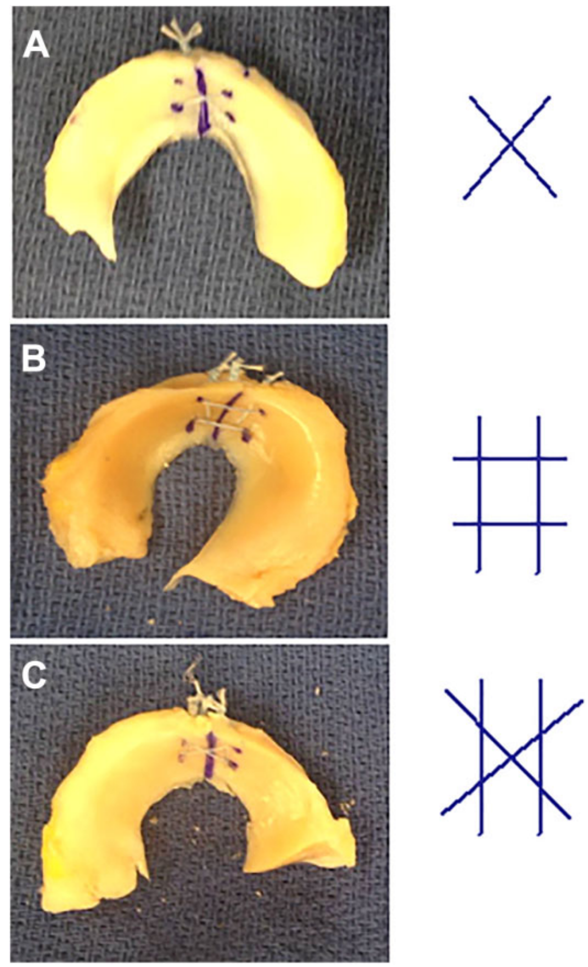

Figure 1. (A) The cross-suture repair first described by Matsubara et al.[23] (B) The novel hashtag technique. (C) The novel crosstag technique.

METHODS

A total of 36 fresh-frozen cadaveric tibial plateaus containing intact menisci were obtained for this study (Musculoskeletal Transplant Foundation). Fourteen specimens were female and 22 were male. The mean age of the cadaveric specimens was 51 years. The menisci were divided into 3 groups (n = 12 in each group) and thoroughly inspected for degenerative changes or evidence of prior surgery. A full-thickness radial tear was made in the midbody of the lateral meniscus with a No. 10 blade scalpel. Repair order was decided by random selection from an opaque envelope. The 3 groups consisted of the following: cross-suture repair (as described by Matsubara et al[23]), hashtag repair, and crosstag repair (Figure 1). For the

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hashtag and crosstag repair techniques, 1 vertical mattress suture was placed first on either side of the radial tear (total of 2 sutures). For the crosstag technique, the sutures were placed obliquely from the medial and lateral edges of the tear over the vertical mattress sutures. For the hashtag technique, the sutures were placed horizontally to the medial and lateral edges of the tear over the vertical mattress sutures. Placed on each side of the tear, the vertical mattress sutures were positioned such that when combined with the horizontal sutures (hashtag) and the cross sutures (crosstag), they would theoretically serve as a ripstop to increase the strength and stability of the repair. All repairs were performed with an inside-out technique with the same suture (2-0 Ultrabraid; Smith & Nephew). The vertical mattress sutures were placed 3 mm and 6 mm from the meniscal rim and 3 mm from the tear. The horizontal and oblique sutures were placed over the vertical mattress sutures at 3 mm and 6 mm from the meniscal rim and 3 mm from the tear. After the repairs were performed, special care was taken to remove the menisci from the tibial plateau. Menisci were kept well hydrated and wrapped in saline-soaked gauze as they awaited testing.

An Instron E10000 materials testing machine was used for the biomechanics testing. Novel clamps were designed and fabricated (Micro Fixtures) to ensure adequate grip and to prevent slippage. Prior to testing, the medial menisci underwent pilot testing to ensure that the machine and setup were functioning properly. We sought to replicate the biomechanical testing performed by Matsubara et al.[23] The repaired lateral menisci were first clamped securely to the materials testing machine and were subjected to cyclic loading at 1 Hz between 5 N and 30 N for 500 cycles (Figure 2).

Load-to-failure testing was performed immediately after cyclic testing. The menisci were subjected to tension at a displacement rate of 5 mm per minute.[23] After testing, mode of failure was assessed with visual inspection.

Statistical Analysis

Data were analyzed with SPSS (v 17.0; IBM). An a priori power analysis (alpha = 0.05, power = 0.80) with related past research[23] was conducted, which called for 22 menisci per suture pattern group (for a total of 66 total menisci). However, a statistical analysis was conducted once there were 12 menisci in each group (36 total), which revealed that sufficient power (0.89) had already been achieved; therefore, no more menisci were tested. Normality of the data was assessed with the Shapiro-Wilk test ($P > .05$). Normality was not met, so instead of Student *t* tests, Kruskal-Wallis tests determined if there was a significant difference in outcomes among the 3 suture patterns ($P < .05$). If and when a group was found to be significantly different, a post hoc Mann-Whitney test was used to find where the significant differences occurred ($P < .05$). Means, standard deviations, and *P* values are all reported.

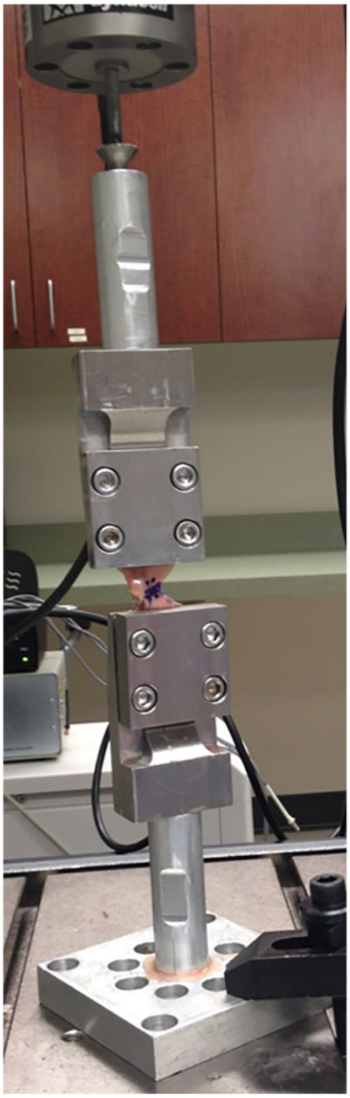

Figure 2. Biomechanics setup of the meniscus attached to the materials testing machine (Instron E10000).

RESULTS

Displacement After Cyclic Loading

The cross-suture repair displaced 4.78 ± 1.65 mm; hashtag suture, 2.42 ± 1.13 mm; and the crosstag suture, 3.13 ± 1.77 mm. Compared with the cross-suture repair, the hashtag and crosstag repairs both resulted in significantly less displacement ($P = .003$ and .024, respectively). There was no statistical difference between the hashtag and crosstag repairs ($P = .386$) (Figure 3).

Load at 3 mm of Displacement

The cross-suture technique required 58.31 ± 17.08 N to displace the repair 3 mm; the hashtag, 64.16 ± 10.77 N; and the crosstag, 54.16 ± 5.81 N. There was no difference

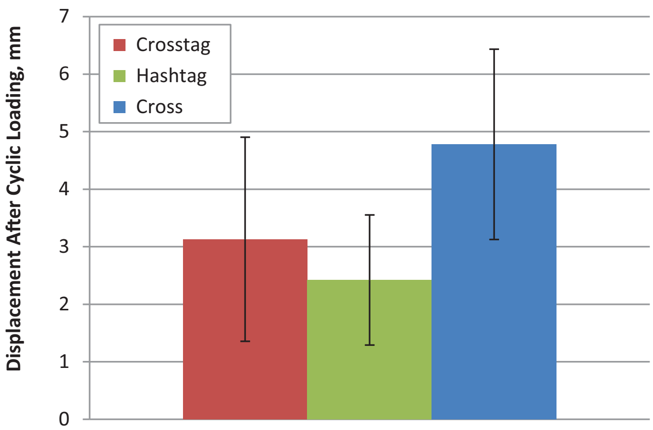

Figure 3. The displacement after 500 cycles of loading for the 3 repair techniques. Values are presented as mean ± SD.

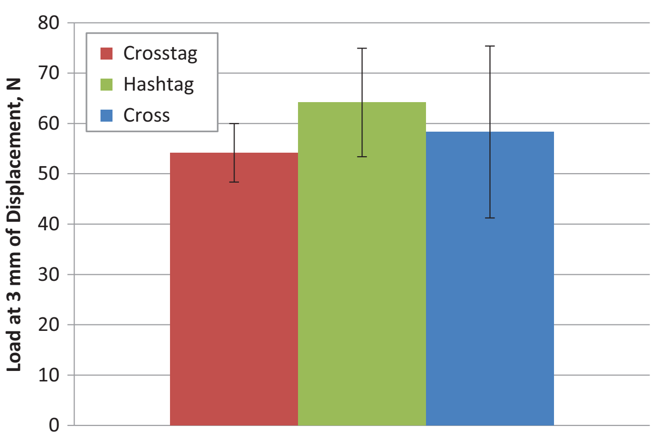

Figure 4. The load at 3 mm of displacement for the 3 repair techniques. Values are presented as mean ± SD.

between the hashtag or crosstag technique versus the cross-suture technique (P = .564 and .094, respectively). The hashtag technique required a significantly higher load to displace the repair 3 mm when compared with the crosstag technique (P = .015) (Figure 4).

Load to Failure

Load to failure for the cross-suture technique was 81.43 ± 14.31 N; for the hashtag, 86.08 ± 23.58 N; and for the crosstag, 62.50 ± 12.15 N. Statistically, there was no difference between the hashtag and cross-suture repairs (P = .564). The cross-suture and hashtag repairs both resulted in a higher load to failure when compared with the crosstag repair (P = .009 and .009, respectively) (Figures 5 and 6).

Displacement After Load to Failure

The displacement after load to failure for the cross-suture repair was 10.78 ± 3.65 mm; for the hashtag, 10.25 ±

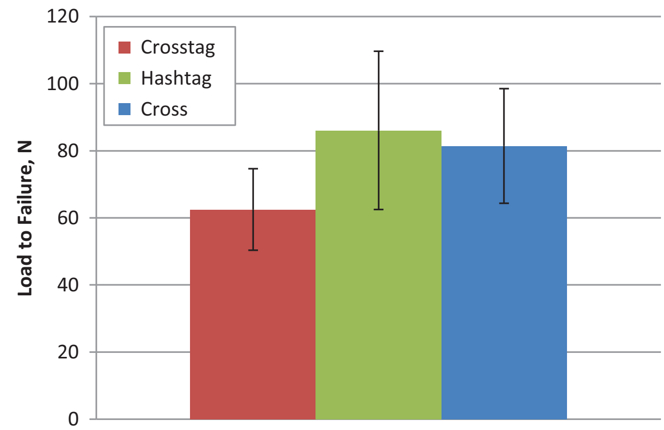

Figure 5. The load to failure for the 3 repair techniques. Values are presented as mean ± SD.

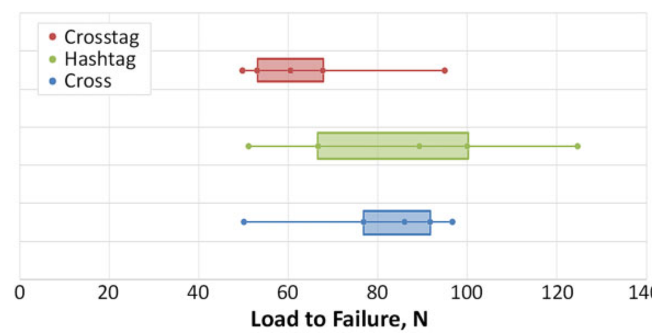

Figure 6. Box plot of ultimate failure for the 3 repair techniques. Values are presented as mean ± SD.

4.10 mm; and for the crosstag, 8.30 ± 2.44 mm. The repairs demonstrated no statistical difference (P = .226).

Stiffness

The stiffness for the cross-suture repair was 8.48 ± 2.96 N/mm; for the hashtag, 9.30 ± 3.31 N/mm; and for the crosstag, 8.13 ± 2.96 N/mm. The repairs demonstrated no statistical difference (P = .976).

Mode of Failure

Among the menisci tested, 30 failed owing to tissue failure and 6 to suture breakage (n = 3, cross-suture; n = 2, hashtag; n = 1, crosstag).

DISCUSSION

The purpose of our study was to investigate the biomechanical stability of 2 novel techniques to repair radial meniscal tears and compare them with the cross-suture repair technique described by Matsubara et al.[23] Using cadaveric menisci, we found that the hashtag and crosstag repairs both exhibited significantly less displacement after cyclic loading when compared with the cross-suture repair. Neither novel technique differed from the cross-suture repair in load at 3-mm displacement. In addition, displacement after load to failure and stiffness testing did not differ between the repair methods. Matsubara et al[23] found their cross-suture repair technique to be superior to a previously described double horizontal mattress repair technique.[17] In that study, the ultimate load to failure and displacement after cyclic loading testing for a cross-suture repair were 78.96 ± 19.27 N and 5.74 ± 1.84 mm, respectively, similar to our study: 81.43 ± 14.31 N and 4.78 ± 1.65 mm. This suggests that our study design and results well duplicated the methods described by Matsubara et al[23] and represent a valid comparison.

Herbort et al[17] demonstrated that a double horizontal suture repair was superior to a single-loop horizontal suture repair in load to failure, repair displacement, and stiffness. They also found that suture placement closer to the meniscal rim demonstrated superior biomechanics. Bedi et al[8] and Ode et al[27] examined the contact mechanics of lateral meniscal repairs of large radial tears with the double horizontal suture technique. They found that while peak contact pressure was significantly reduced with repair, peak contact area could not be restored to the native condition. Matsubara et al[23] demonstrated that, compared with the double horizontal mattress repair method, the cross-suture technique resulted in significantly less displacement after cyclic loading, a higher load to failure, and greater stiffness.

Interest in improving the mechanical properties of radial meniscus tear repairs has extended to transtibial repair methods as described biomechanically by Bhatia et al[11] and clinically by Cinque et al.[14] However, the biomechanical study compared transtibial repair with the horizontal mattress configuration, which was not included in our study, thereby precluding comparison.

The sequelae of lateral meniscectomies have created an impetus to preserve as much tissue as possible, as well as a need to develop a repair method that approaches the native meniscus.[32] Matsubara et al[23] theorized that the superior biomechanics of the cross-suture repair may be due to the oblique orientation of the sutures in relation to the collagen fibers within the meniscus.[15] Perhaps of equal importance to stability is a design construct that best counteracts the dynamic, directional force vectors to which menisci are exposed that threaten the success of a repair. Our hashtag and crosstag techniques incorporated vertical sutures in a ripstop-type configuration and double horizontal mattress or double oblique mattress sutures, respectively. This produced comparable but not superior stability in most of the tested biomechanical parameters. Importantly, compared with the cross-suture technique, the hashtag and crosstag repairs both resulted in significantly less displacement after cyclic loading.

Cyclic loading is believed to most closely resemble the kinetic demands that the repair would face under in vivo conditions.[17,23] We used a protocol that approximates previous biomechanical meniscus studies: 1 Hz between 5 and 30 N for 500 cycles. Reducing displacement under load may allow for better healing and improved contact mechanics and clinical outcomes. Further studies are needed to determine whether any of the 3 radial tear repair techniques restores dynamic contact mechanics of the intact knee, the findings of which may call for in vivo animal model testing. If the crosstag and hashtag repair techniques demonstrate clinically superior healing in radial tears, extra time spent in the operating room and increased cost of the suture may be justified.

Limitations

Our study contained several limitations. The first is that it was done on cadaveric tissue, which is avascular, sterilized, processed, frozen, and rethawed—all of which may alter the structural integrity as opposed to live meniscal tissue. The menisci were tested in isolation devoid of variables such as supporting soft tissue, synovial fluid, and blood supply. Because this was an in vitro study tested at time zero, there was no healing factor that would ideally be present in an in vivo setting. It is important to remember that radial tears extend into the avascular zone and have less capacity to heal than do peripheral longitudinal tears.[5] The repairs were performed on dissected menisci and may differ from achievable repairs performed arthroscopically. As with similar studies, tension load was applied perpendicular to the meniscal tear, which placed the integrity of the repair at greater risk than it would likely encounter in vivo. Comparing the 3 repairs completed in our study with those employed by Matsubara et al[23] was important in determining the superior repair construct for full-thickness radial tears. In addition, our in vitro study was not designed to re-create the kinematics of an intact knee joint. Loading of the Instron materials testing machine does not simulate actual loading during the gait cycle. The load at 3 mm of displacement was measured by displacement of the Instron clamps, which fails to account for elastic deformation of the suture material or the actual gap at the repair site. Finally, our load-to-failure test was performed after cyclic loading and thus cannot be considered “true” load to failure.

CONCLUSION

The hashtag and crosstag suture techniques were not statistically significantly different from the cross-suture technique with respect to failure or stiffness, but both were statistically superior to the cross-suture repair in terms of displacement after cyclic loading. We believe that displacement after cyclic loading may be the most important factor in consideration of a repair technique in the meniscus.

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